Noise characterization of RF stressed GaN HEMTs

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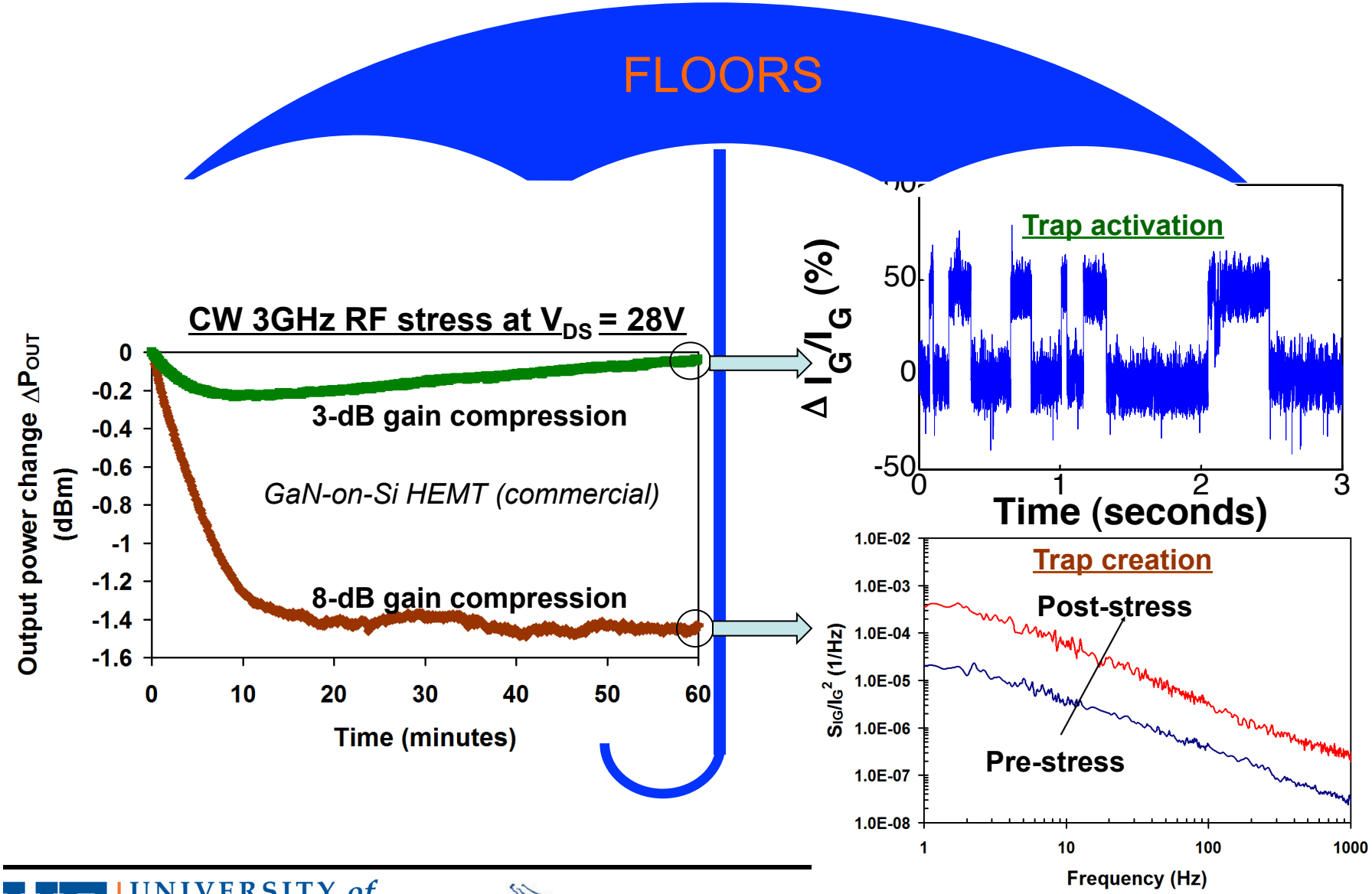
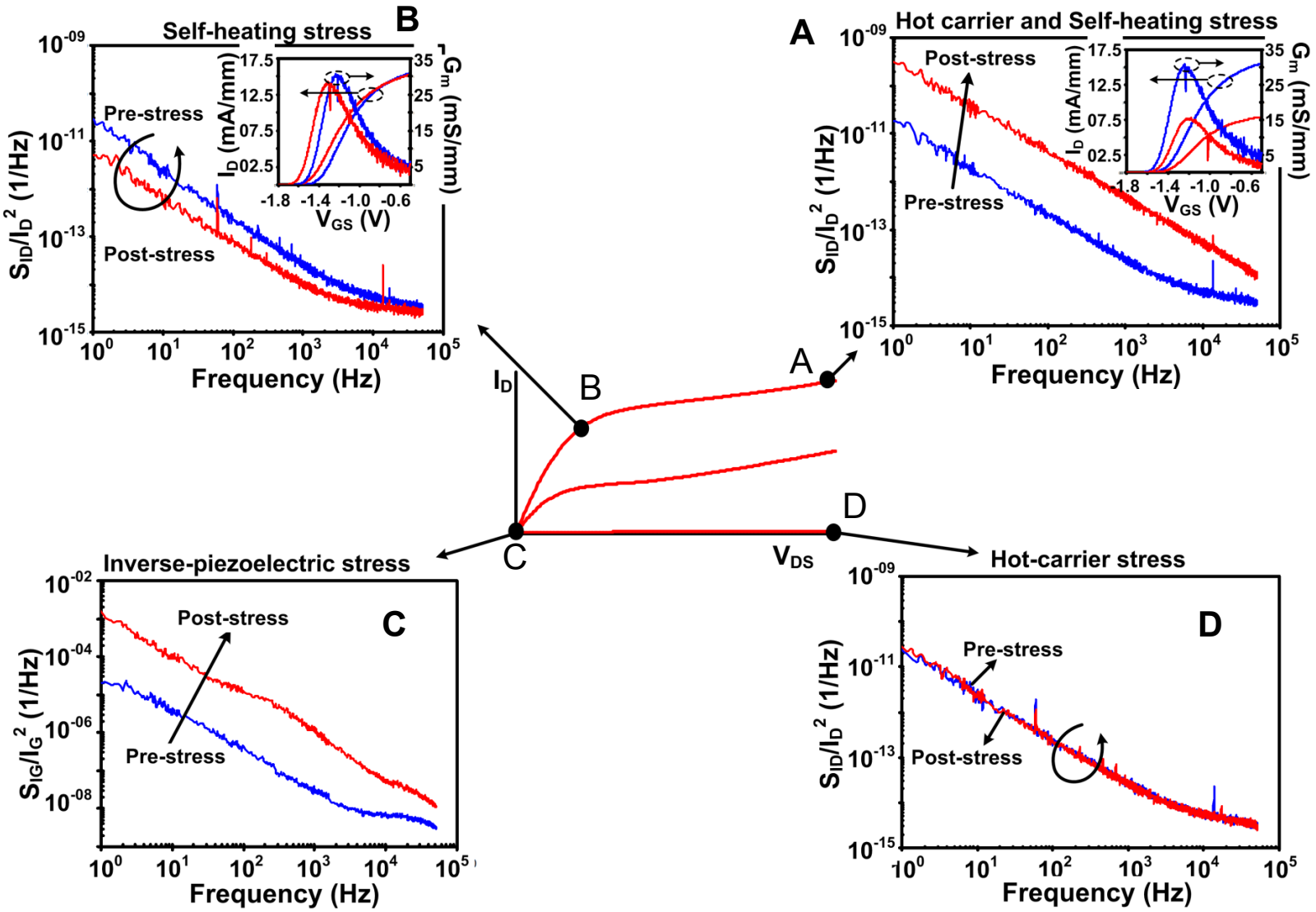
Overview

- Introduction/Review
  - MURI umbrella
- Experimental details
- RF stress experiment
  - RF characteristics
  - Noise characteristics
- Analysis
- Conclusions

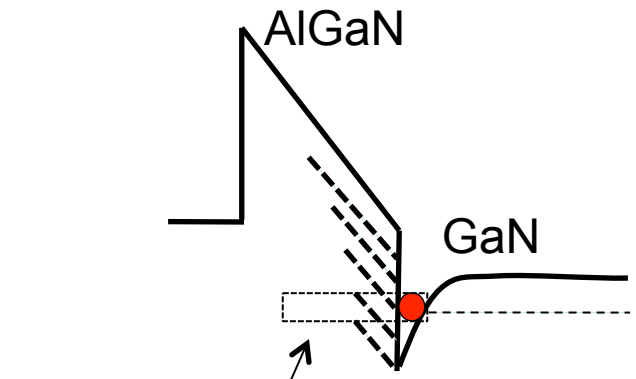
Noise spectroscopy



Review


B
Self-heating stress
Pre-stress
Post-stress
S_{ID}/I_D^2 (1/Hz)
I_D (mA/mm)
G_m (mS/mm)
V_{GS} (V)
Frequency (Hz)
A
Hot carrier and Self-heating stress
Post-stress
Pre-stress
S_{ID}/I_D^2 (1/Hz)
I_D (mA/mm)
G_m (mS/mm)
V_{GS} (V)
Frequency (Hz)
I_D
V_{DS}
A
B
C
D
C
Inverse-piezoelectric stress
Post-stress
Pre-stress
S_{IG}/I_G^2 (1/Hz)
Frequency (Hz)
D
Hot-carrier stress
Pre-stress
Post-stress
S_{ID}/I_D^2 (1/Hz)
Frequency (Hz)

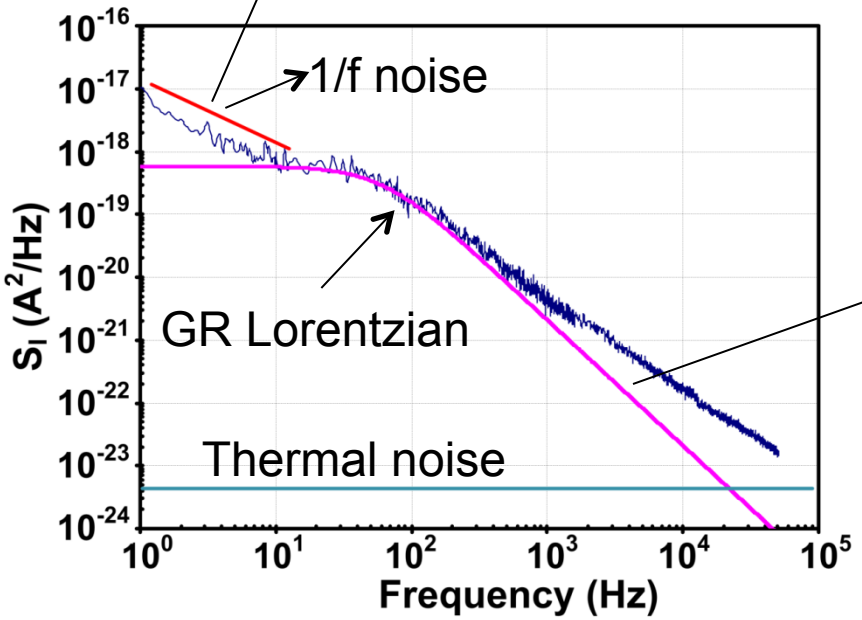
Defect spectroscopy using noise

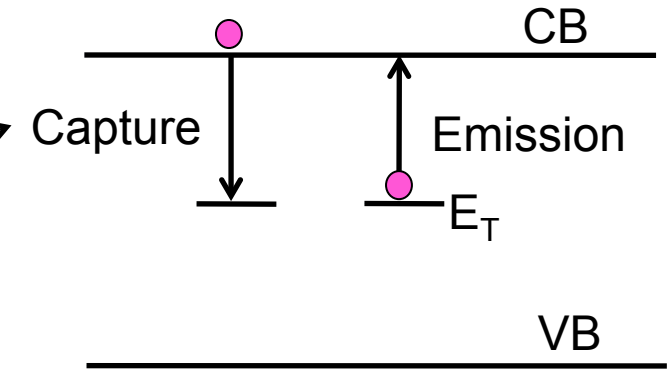


- $\frac{1}{f^{\gamma}}$ noise is an excellent *interface defect* quality indicator for the channel.

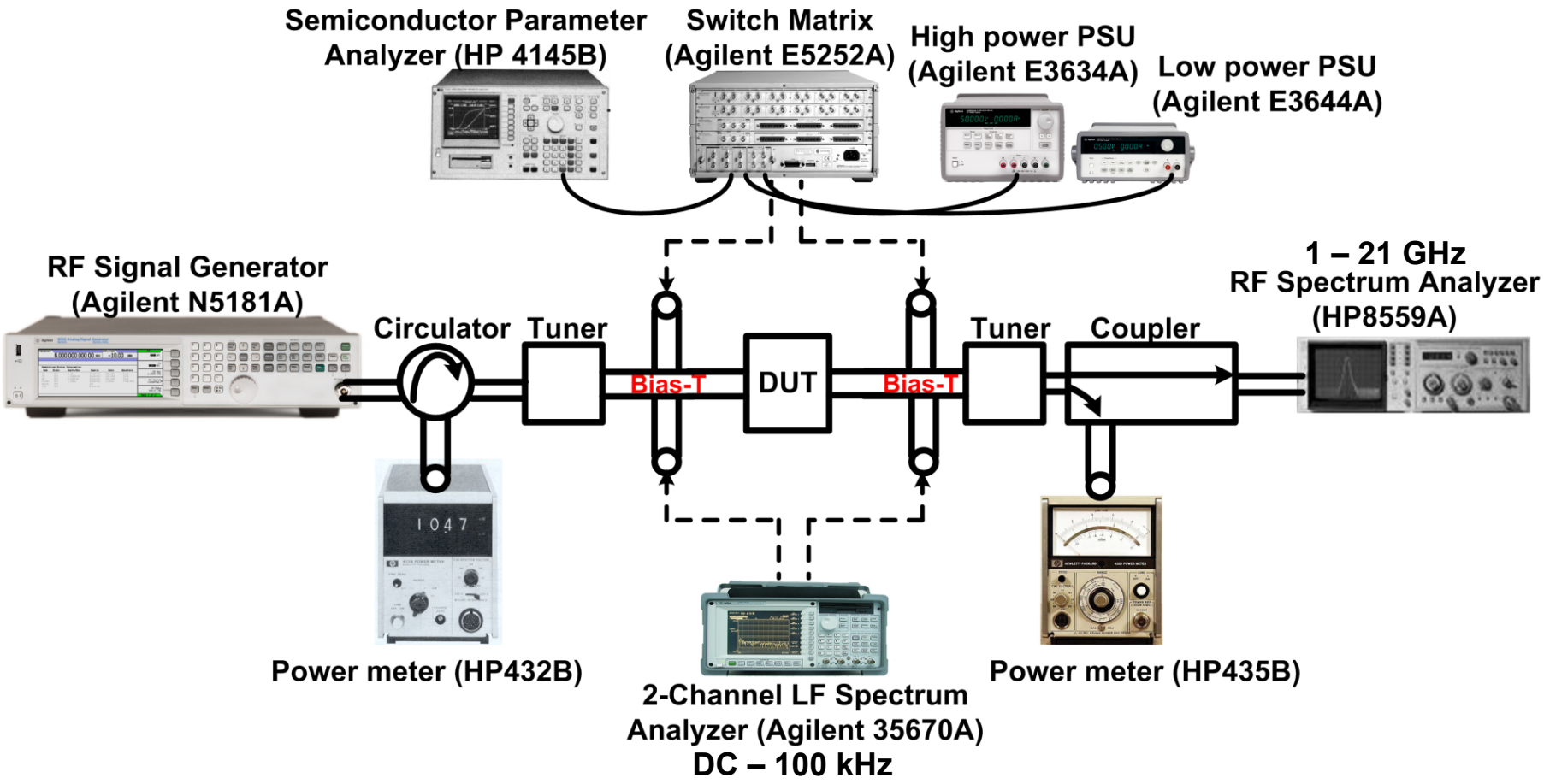
$$\frac{S_I}{I^2} = \frac{\alpha_H}{Nf}$$ where α_H is the Hooge parameter

- Lorentzian due to random telegraph noise is an excellent *point defect* probe.

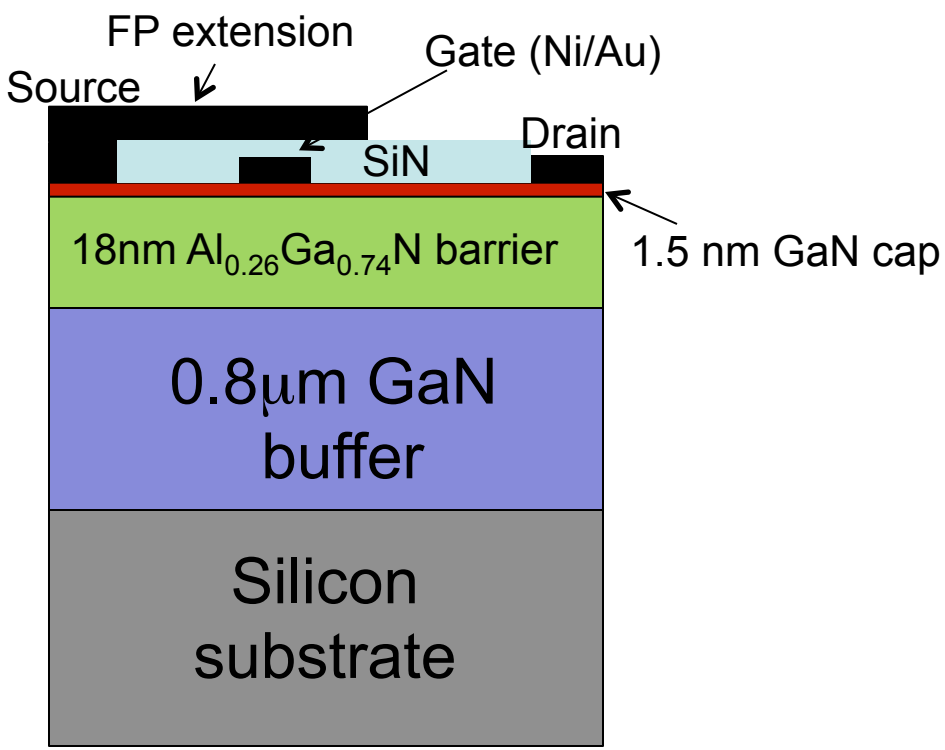




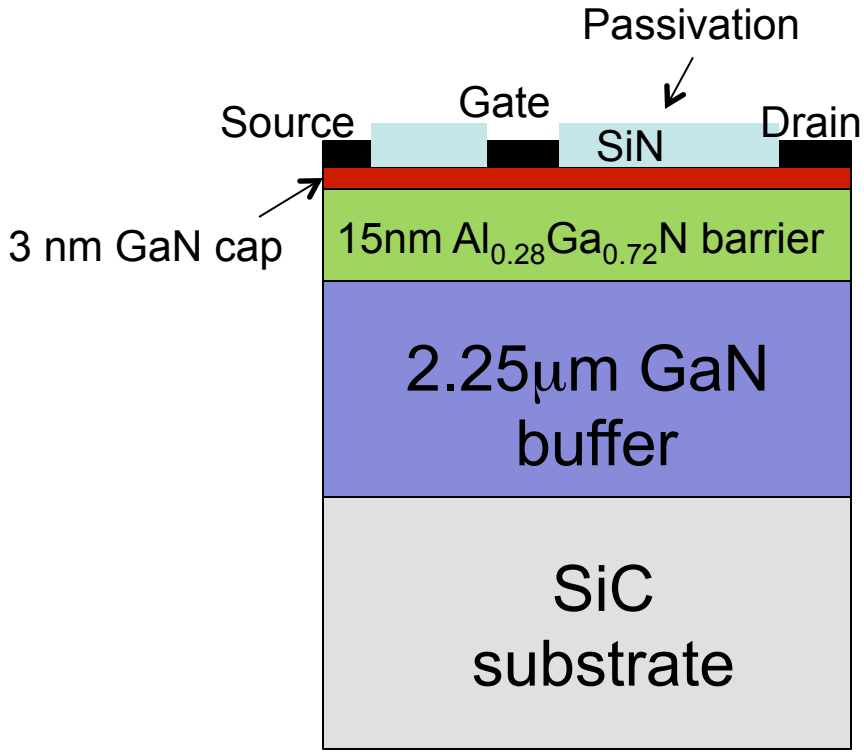
Experimental setup



Devices under study

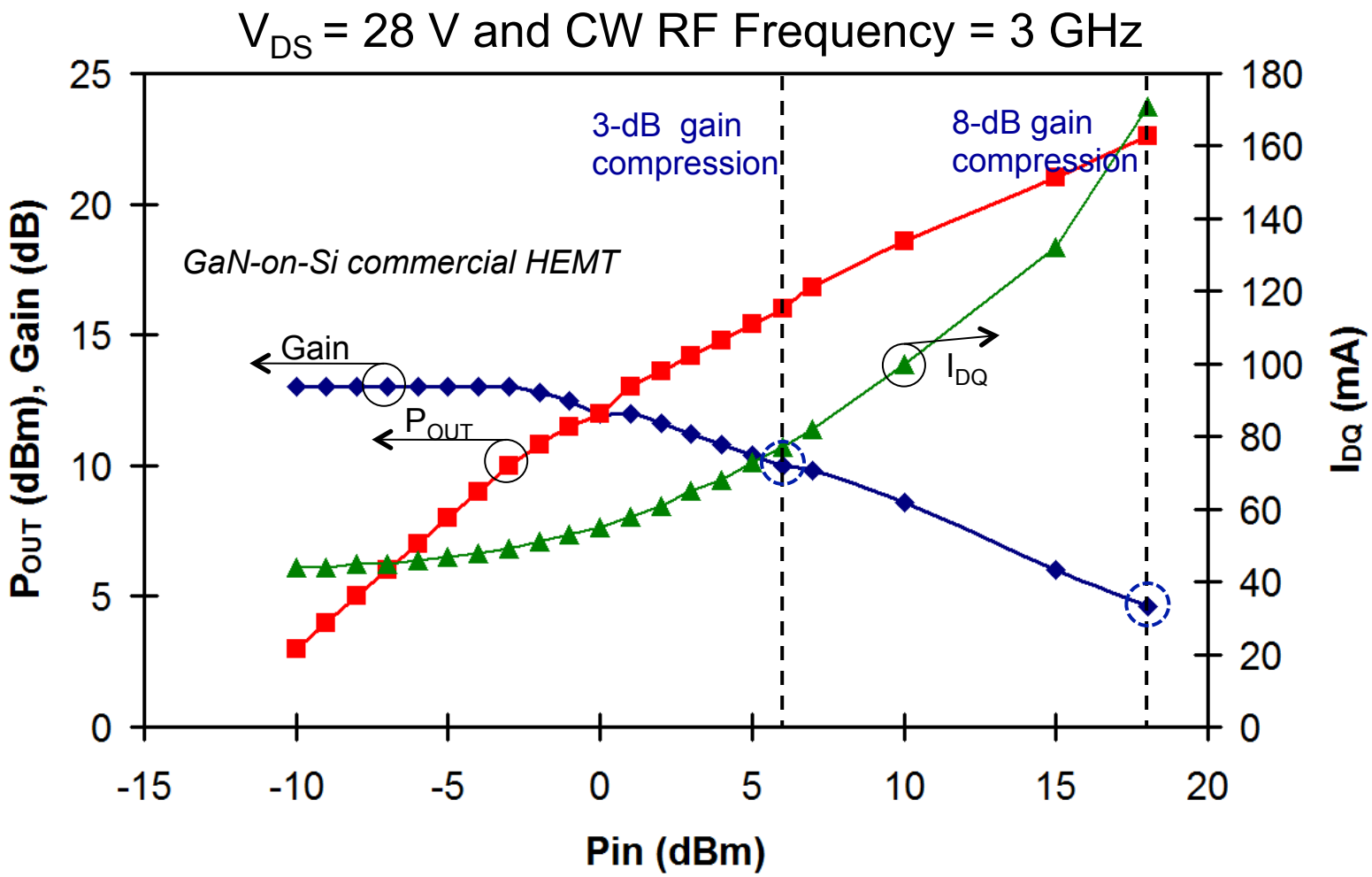


- Commercial device
- Gate length (L_G ~ 0.65 μm)
- 10 gate finger device with 2 mm periphery.
- Ceramic packaged.

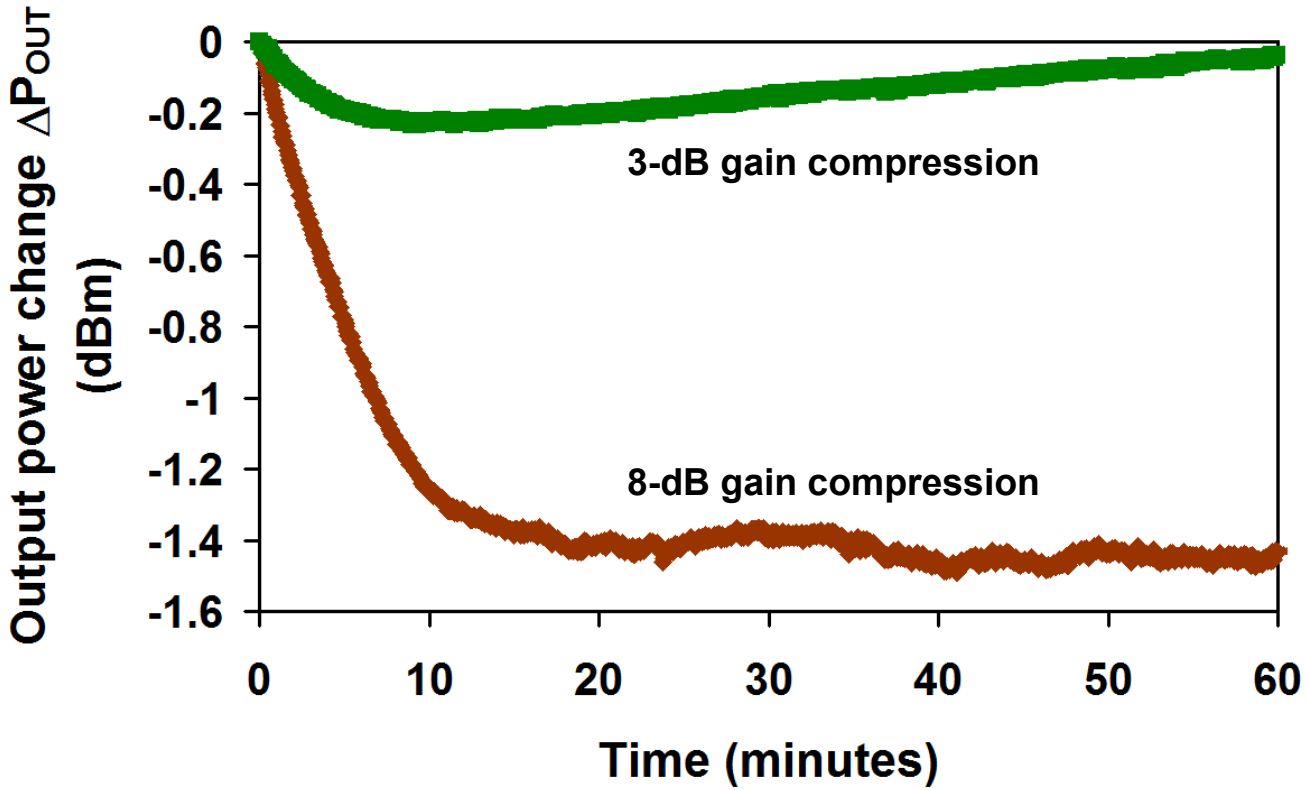


- AFRL sample
- Gate length (L_G ~ 0.1 μm)
- 2 gate finger device with W_G ~ 160 μm
- Ceramic packaged.

RF power characteristics



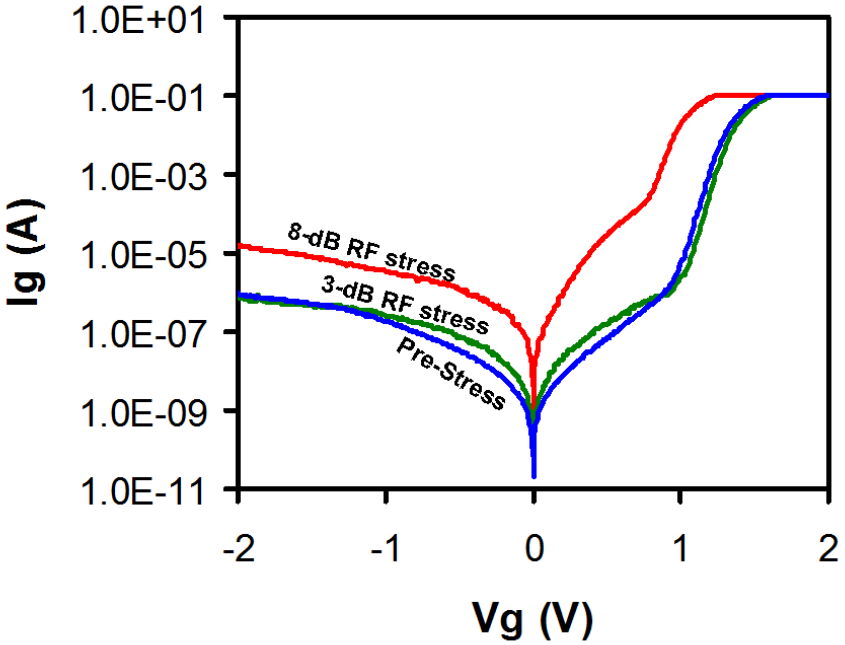
RF stress



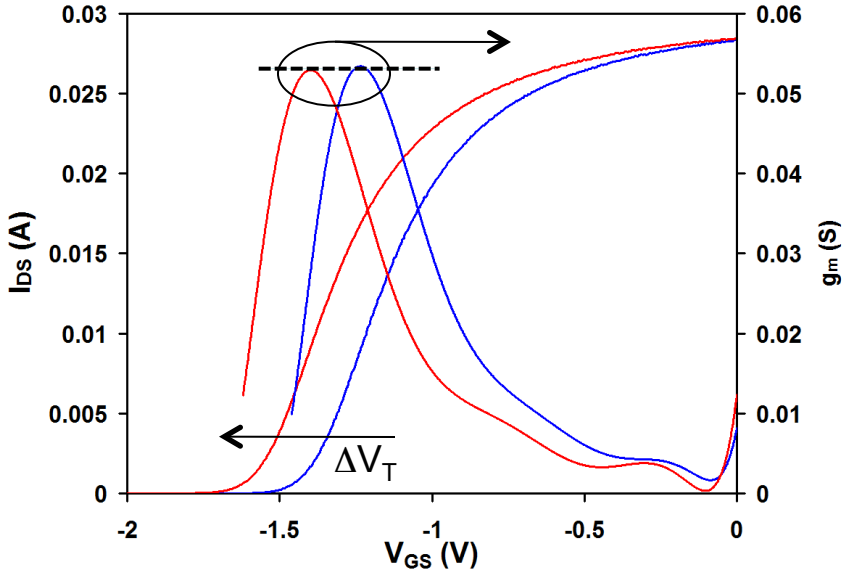
- 3-dB compression leads to negligible change in output characteristics
- 8-dB compression induces a major degradation of ~ 1.5 dBm in the first 20 minutes

DC characteristics

Gate region

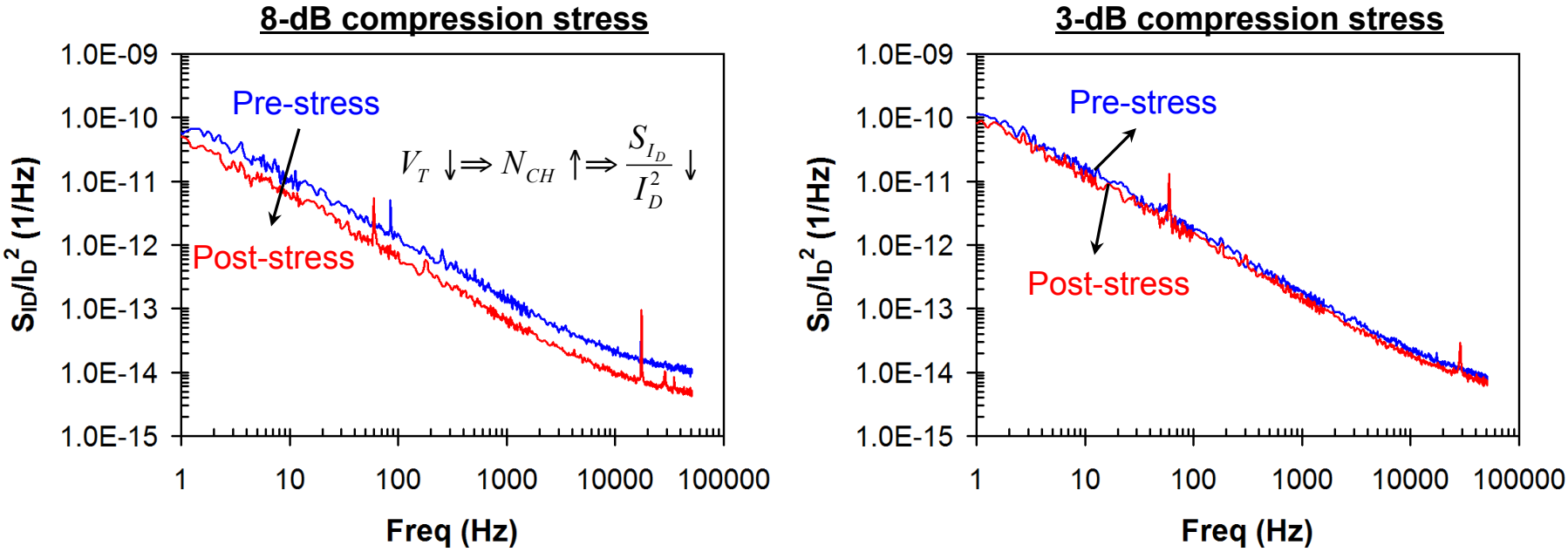


Channel region (8-dB stress)



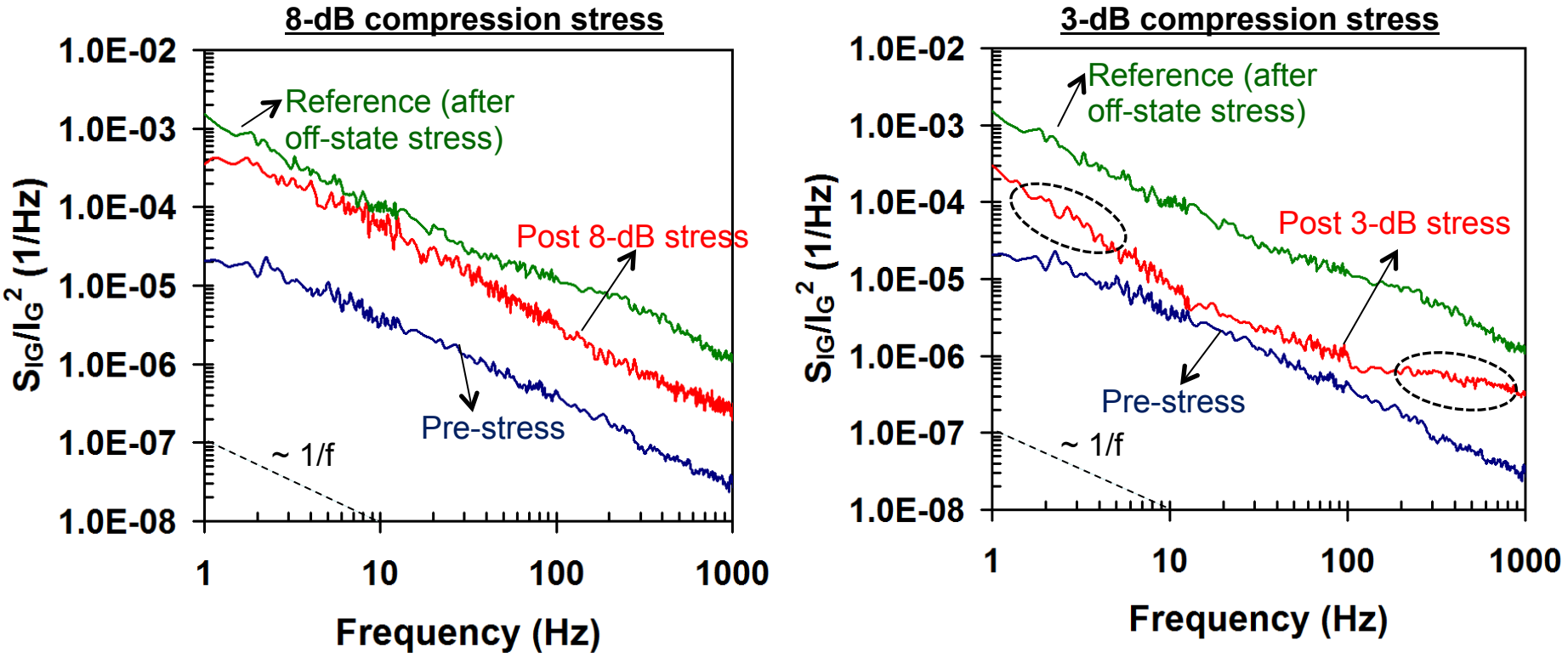
- 8-dB compression RF stress
  - Gate leakage current degrades *permanently*
  - Threshold voltage shifts permanently without affecting the peak transconductance
- 3-dB compression doesn't not effect the DC characteristics significantly

Channel noise



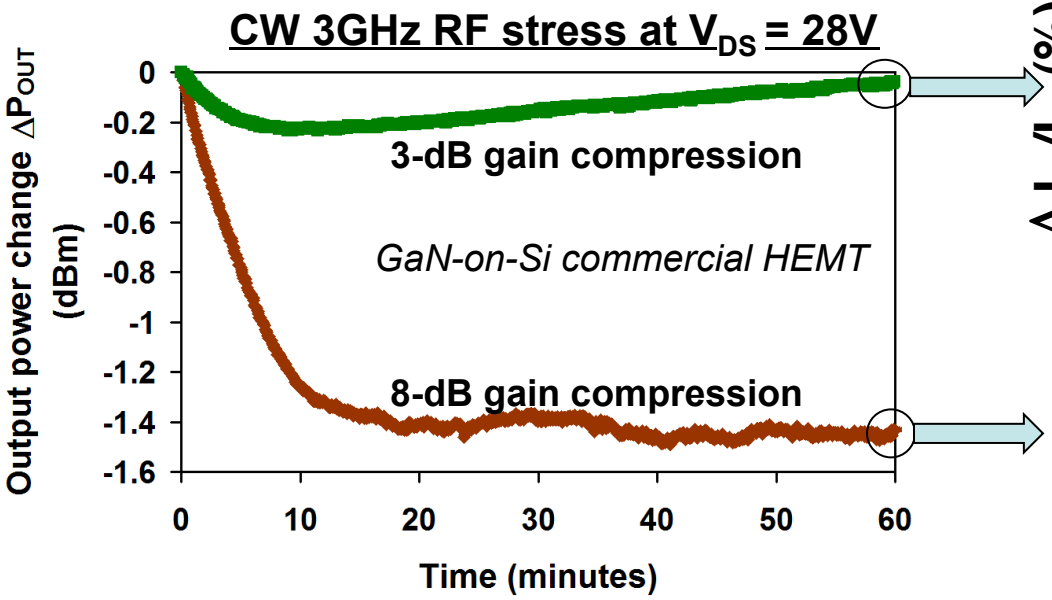
- Hooge parameter (α_H) ~ 10^{-3} remains the same for both stresses
  - No permanent degradation in the channel

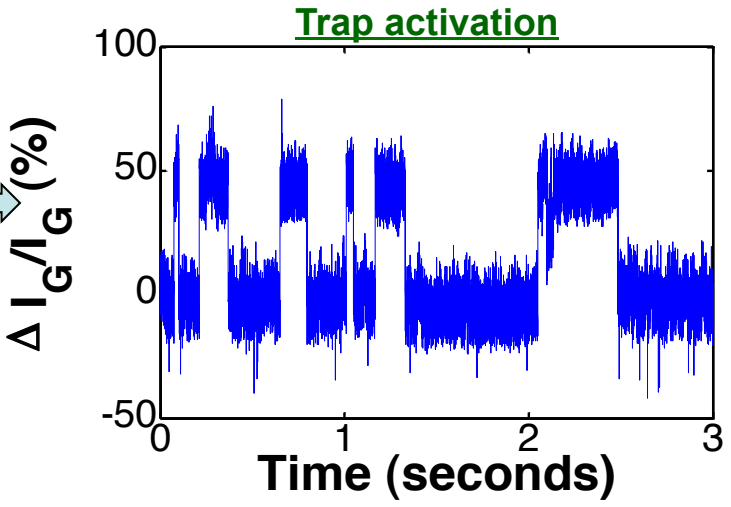
Gate noise

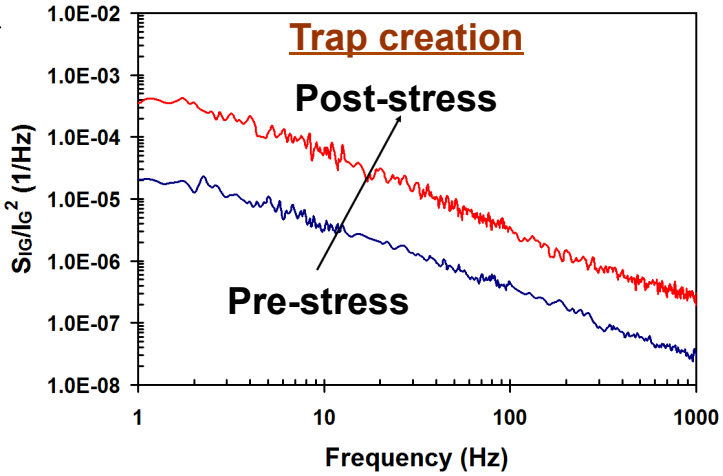


- 8-dB compression stress causes irreversible increase in 1/f noise similar to the off-state DC stress
- 3-dB compression stress induces unstable Lorentzians (dashed circles) and RTS noise with a small net increase in 1/f noise

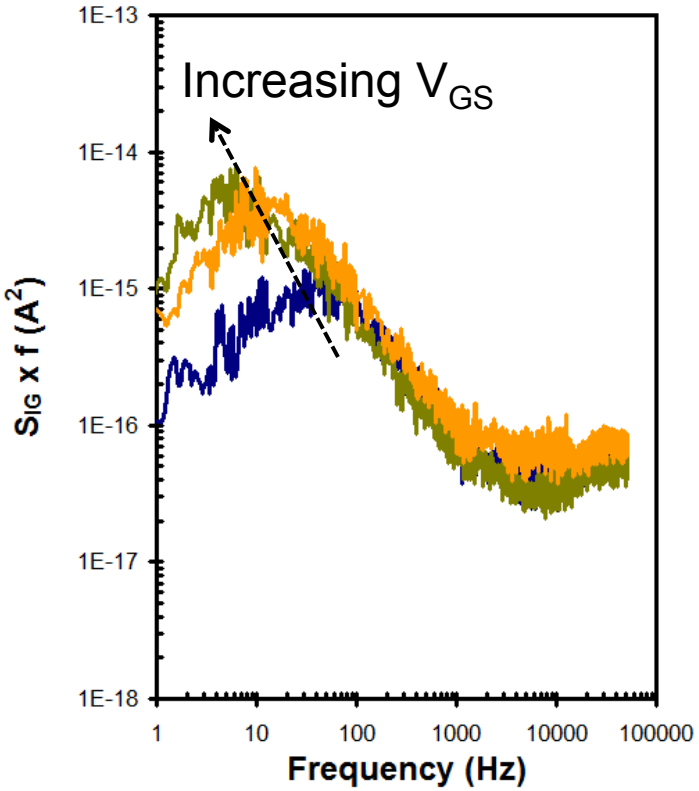
Gate noise characteristics

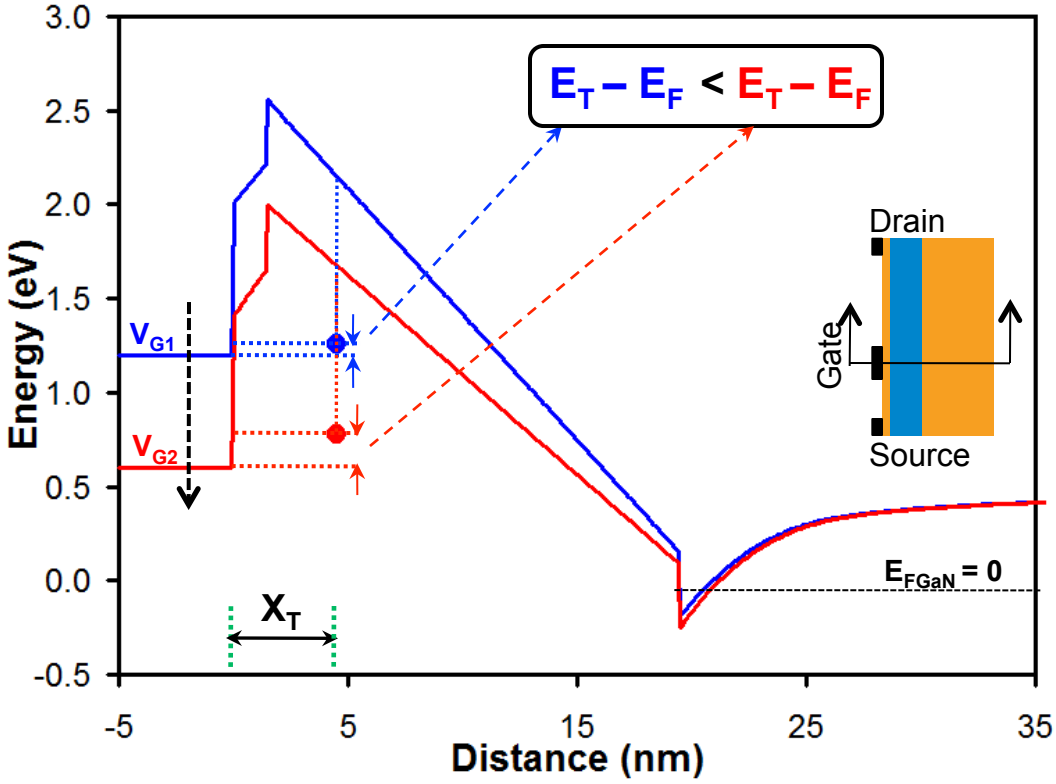






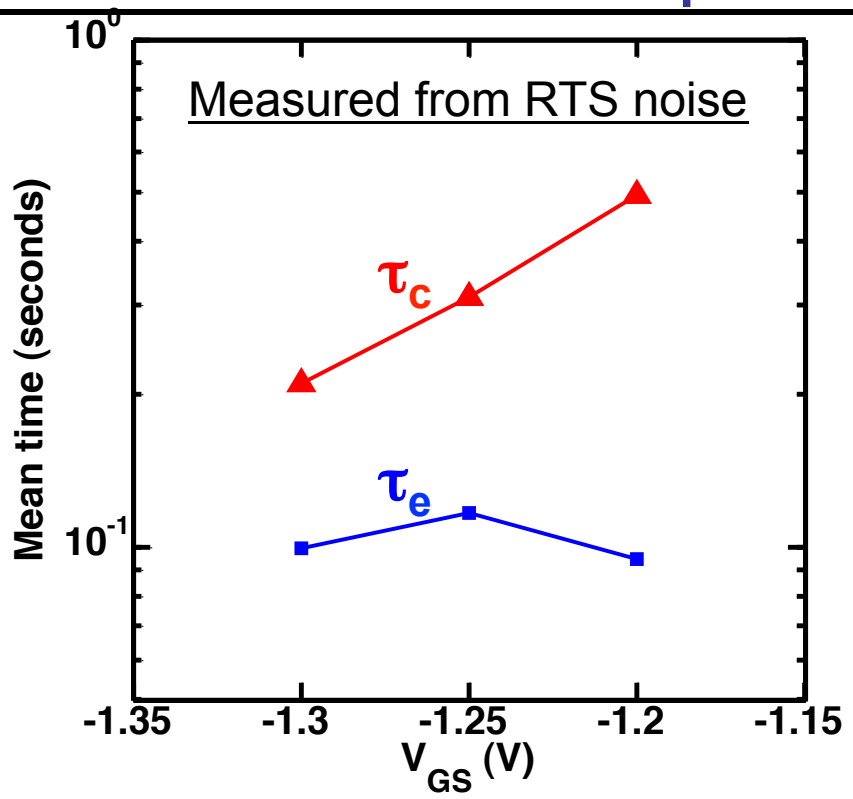
Trap mechanism

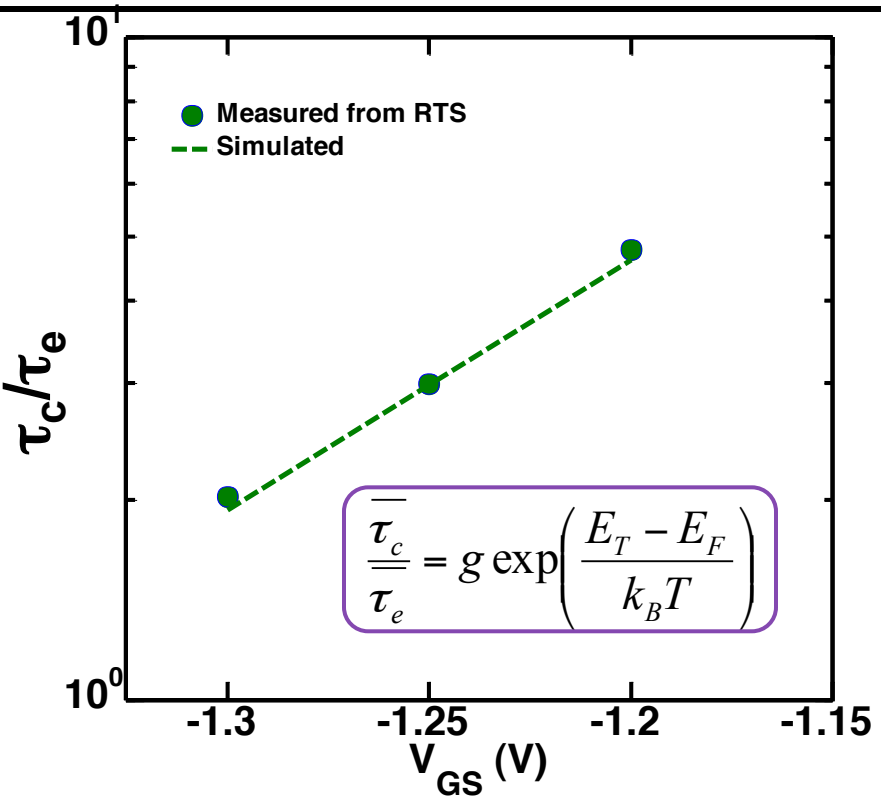




- Increasing gate voltage leads to slowing the characteristic frequency of gate noise
- Defect located near the interface can cause this effect due to bias dependence of the trapping energy level

Trap characteristics





- Extracted parameters
  - Trap distance from Metal/Semiconductor junction (x_T) = **4.5 nm**
  - Trap energy level wrt AlGaN conduction band edge (E_C-E_T) = **0.9 eV**
  - Reported [1],[2] values of 0.8 – 1.0 eV **Ga-vacancies** [1] Rumyantsev et el.(2001)
    [2] Fang et el. (2010)

Conclusions

- Characterized the effect of RF stress on GaN HEMT reliability for various gain compression
- Degradation occurs in the gate stack near the metal/semiconductor interface
  - 1/f noise increased irreversibly
  - Extracted trap location ~ 4.5 nm from the gate
  - Extracted trap activation energy (E_C-E_T) ~ 0.9 eV in AlGaN barrier